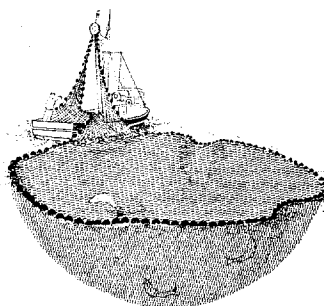
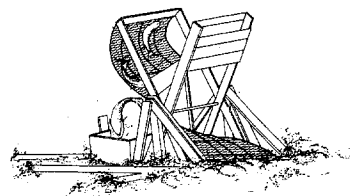
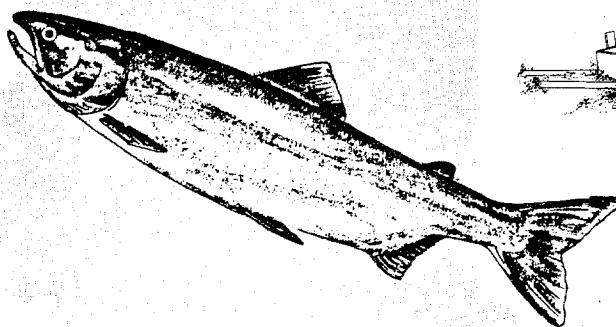
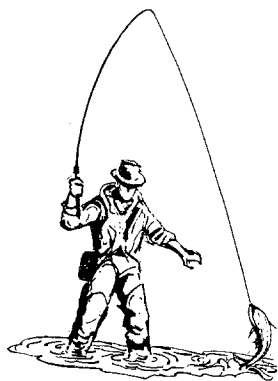


Alaska Fisheries Technical Report Number 3
WINTER WATER AVAILABILITY
ON THE 1002 AREA
OF THE
ARCTIC NATIONAL WILDLIFE REFUGE



May 1989

Region 7
U.S. Fish and Wildlife Service
Department of the Interior

WINTER WATER AVAILABILITY
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Abstract

During March 25-30, 1988, an inventory of winter water availability was conducted within the 1002 area of the Arctic National Wildlife Refuge. A helicopter mounted radar system was used to identify the presence of sub-ice water. Water was found to be widely distributed throughout much of the 1002 area in several settings: springs and associated aufeis formations; lakes; a deep river pool; and localized pools beneath ice pressure ridges occupying braided river floodplains.

Pressure ridge pools accounted for the most frequent and widespread occurrence of water identified during this inventory. They were identified from portions of river drainages where water was previously undocumented during the winter. These small but numerous pools may greatly expand the known distribution of overwinter habitat for fish in this region, especially for small juvenile fish.

A full inventory of winter water presence within the 1002 area was not completed due to gear limitations and time constraints. Recommendations for further investigation and completion of the area wide inventory are made.

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Introduction

Water on the north slope of Alaska is significantly more abundant in summer than in winter (Wilson et al. 1977). During the winter, stream flow ceases in even the largest rivers and ice thickness on lakes and deep river pools reaches a maximum of 1.6 to 2.4 m by late March or April. Within the 1002 area, most lakes do not exceed 2.0 m in depth (Clough et al. 1987), and therefore freeze to the bottom. River pools with sufficient depth to keep from freezing to the bottom have been documented only from that portion of the Canning River near the southern 1002 boundary (Smith and Glesne 1983). Perennial springs are the only documented source of flowing water, which rapidly cools and freezes, forming large icings or aufeis areas that may reach a thickness of 4.9 m and cover about 5 km². Wilson et al. (1977) identified five springs within the 1002 area; two on the Katakturuk River, Sadlerochit Spring, Hulahula Spring at Fish Hole 1, and Okerokovik Spring. In addition, icings have been identified on the Canning, Tamayariak, and Sadlerochit rivers (Wilson et al. 1977, Dean 1984) that indicate the presence of spring flow.

Overwintering habitat for freshwater and anadromous fishes on the north slope is reported to be restricted to perennial springs and to lakes and river pools with sufficient depth to prevent freezing to the substrate (Bendock and Burr 1984, Clough et al. 1987, Schmidt et al. 1989). Summer fish use has been documented from only six lakes within the 1002 area (West and Fruge in preparation) which may provide overwintering habitat. Water depth in excess of 2.5 m was measured in the largest of the six lakes in September 1987 (Lyons and Elliott 1987). Radio-tagged Arctic grayling (Thymallus arcticus) were described holding in portions of four drainages

within the 1002 area during the winter: the Canning, Sadlerochit, Hulahula, and Okpilak rivers (Wiswar et al. in preparation). However, no deep pools have been documented in the vicinity of these areas and the overwinter survival of those fish was in doubt. Within the 1002 area, the Canning River, Sadlerochit Spring, and Hulahula Spring at Fish Hole 1 have been identified as overwintering areas for fish and may be critical for their survival (Wilson and Kelly in preparation).

Proposed oil and gas exploration and development activity on the 1002 area of the Arctic National Wildlife Refuge will require substantial quantities of water. Historically, industrial water needs for oil exploration on the north slope have been highest during the winter, when drilling activities occur. In addition to the water needed for drilling, ice road and airstrip construction and maintenance also require large volumes of water. The quantity of water required for the various exploration activities is reported by Clough et al. (1987).

The greatest potential for conflict between maintenance of aquatic habitat and industrial use of water is during the winter when the amount of unfrozen water is greatly reduced and much of the water is critical to overwinter survival of fish. The U.S. Fish and Wildlife Service, Branch of Water Resources Operations, and the U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, agreed in 1988 to conduct a cooperative investigation of the distribution of water within the 1002 area of the Arctic National Wildlife Refuge during late winter. The objective of this study is to provide a qualitative assessment of the availability of winter water when ice thickness is at a maximum.

Study Area

The 1002 area of the Arctic National Wildlife Refuge encompasses about 627,300 ha of the coastal plain between the Brooks Range and the Beaufort Sea (Figure 1). All rivers in the 1002 area generally flow in a northerly direction. The larger drainages transect the area, originating in the mountains to the south. Smaller drainages originate in the foothill province near the southern 1002 boundary. The drainages investigated during this study were the Canning, Tamayariak, Katakturuk, Sadlerochit, Hulahula, Okpilak, Jago, and Niguanak rivers.

The Canning River, the largest river flowing across the 1002 area, occupies two distinct floodplain configurations. The upper portion, between the southern 1002 boundary and latitude $69^{\circ}55'N$, is characterized by a relatively narrow floodplain confined by the foothills of the Sadlerochit Mountains. The river exhibits some braiding in the upper part of this reach, but is confined to one or two primary channels below the braided portion. North of latitude $69^{\circ}55'$, the river spreads out into a broad, highly braided floodplain. Between the lower extent of the highly braided area and its delta, the Canning River flows for about 9.7 km through one to three broad, low gradient channels. The eastern channels of the Canning and the Tamayariak River enter the main channel of the Canning River within the lower 4.8 km of the river.

The Tamayariak River, a tributary to the Canning River, originates in the Sadlerochit Mountains, south of the 1002 boundary. The largest tributary, the West Fork of the Tamayariak River, enters the mainstem about 13 km above its mouth. Within the 1002 area, both the mainstem and the West

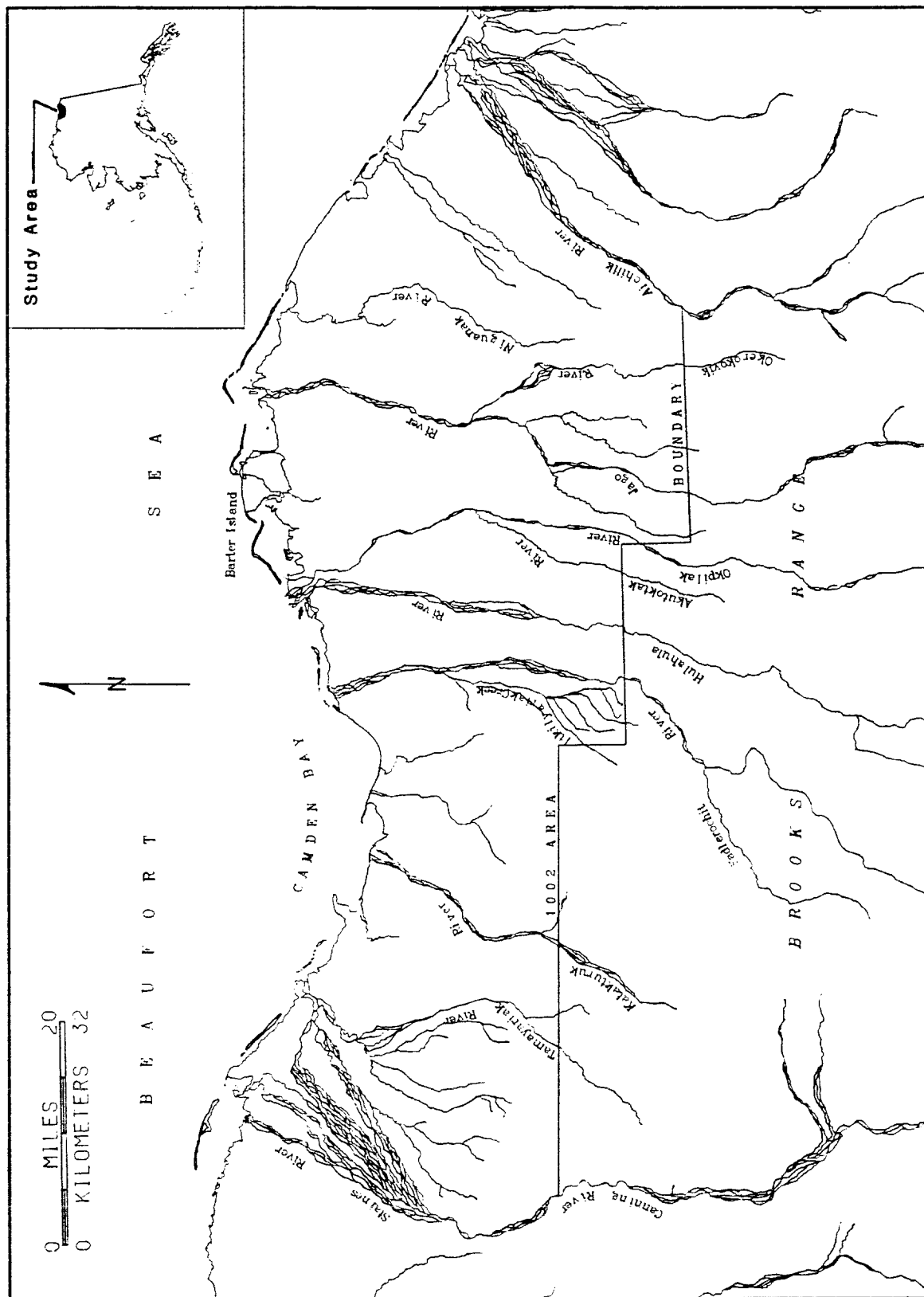


Figure 1.--Location of the 1002 study area and major river drainages.

Fork are characterized by braided channels upstream from their confluence. Below the West Fork confluence, the mainstem is almost entirely confined in a single, broadly meandering channel.

The Katakturuk River originates south of the Sadlerochit Mountains, flows through a cut in the mountain range, then transects the 1002 area. The entire reach through the study area is characterized by a braided channel within an unvegetated floodplain that increases in width to the north.

The Sadlerochit River originates in the Shublik and Franklin Mountains south of the Sadlerochit Mountains, then flows around the east end of the Sadlerochit Mountains where it enters the 1002 area. About 9 km downstream from the 1002 boundary, the river channel becomes extensively braided and this channel configuration continues for the remaining 36 km to the river's mouth. The largest tributary to the Sadlerochit River, Itkilyariak Creek, originates in the Sadlerochit Mountains and flows north, entering the mainstem about 14 km from the Beaufort Sea. The water from Sadlerochit Spring flows into Itkilyariak Creek about 11 km from the spring source and 17 km from the mouth of Itkilyariak Creek. The stream channel of Itkilyariak Creek downstream from the confluence with Sadlerochit Spring Creek is braided.

The Hulahula River transects the central portion of the 1002 area for a distance of 49 km. Between the southern 1002 boundary and Fish Hole 1, the river flows within a confined floodplain, primarily in a single channel. Downstream from that reach the river flows through a highly braided channel for the remaining 36 km to the Beaufort Sea.

The Okpilak River transects the 1002 area to the east of the Hulahula River for a distance of 55 km. The channel is braided for most of that

distance, becoming progressively more braided in a downstream direction. The Okpilak and Hulahula rivers share a common delta. The Akutoktak River is the largest tributary to the Okpilak River within the 1002 area and enters the mainstem 31 km from the Beaufort Sea.

The Jago River transects the 1002 area for a distance of 69 km, flowing through a highly braided channel for at least the lower 50 km. There are two major tributaries to the Jago River within the study area. The Okerokovik River enters the mainstem from the east about 33 km from the Beaufort Sea and Okpirourak Creek enters from the west about 15 km upstream from the Okerokovik River confluence.

The Niguanak River originates within the 1002 area about 54 km from the coast. This river flows primarily within a single channel for its entire length.

The largest lakes within the 1002 area are confined to two small lowland areas, within 7 km of the coast. Most are within an area 13 km to either side of the mouth of the mainstem Canning River. The other area is between the mouth of the Okpilak River and Barter Island. Most of the remaining lakes in the 1002 area are within an area of low foothills between the Okpilak River and 8 km east of the Niguanak River, extending inland from the coast for about 32 km.

Methods

Prior to the winter season, permanent steel fencepost markers were placed at six locations to provide reference points near potential sites where winter water presence was suspected (Table 1). In addition, transects

Table 1.--Number, location, and figure reference of fenceposts placed adjacent to three 1002 area rivers during 1987.

Fencepost			Figure
Number	River	Map Location	Reference
1	Canning	NE1/4 Sec. 20, T6N, R23E	2
2	Canning	SE1/4 Sec. 8, T8N, R26E	2
3	Canning	SW1/4 Sec. 10, T8N, R26E	2
4	Tamayariak	E1/2 Sec. 29, T8N, R26E	3
5	Sadlerochit	NE1/4 Sec. 9, T7N, R31E	6
6	Sadlerochit	NW1/4 Sec. 4, T7N, R31E	6

were marked on 1:63,360 scale topographic maps to be used as a guide for investigation of the water resources of all major lakes and river drainages within the 1002 area.

During March 25-30, 1988, a helicopter mounted, short pulse radar system was used to measure ice thickness and detect the presence of unfrozen water along established transects. The radar system and its use are described in detail by Arcone et al. (in preparation). Radar data was recorded on a cassette tape recorder. The taped data was later used to produce a graphic record from which sub-ice water presence could be visually identified and ice thickness could be measured. The interpretation of the results of the radar data is by the author based on guidance given by Arcone et al. (in preparation).

Established transects were actually used only in portions of river drainages where rivers were confined to a single channel or where water presence was known to occur or was indicated by aufeis formations. After the first day in the field, an association was made between visually identifiable ice formations (pressure ridges) and the presence of water. Most of the transects after that time were flown over these formations in a longitudinal direction with respect to the river channels. Cross sectional transects were used to delineate the location of water within aufeis formations. Transect locations were identified based on visually recognizable topographic features that could be recognized on the topographic maps. A satellite linked, global positioning system operated from a laptop computer was also used to determine the latitude and longitude coordinates of transect locations when the system operated properly.

Ice thickness was ground truthed and water depth was measured at three locations using a hand auger and weighted tape measure. Water conductivity was measured at two of those locations using a Yellow Springs Instruments Model 33¹ salinity-conductivity-temperature meter.

Results

Water was found throughout much of the 1002 area. Open flowing water was observed at two locations in association with perennial springs. The occurrence of sub-ice water was identified in four settings:

- 1) beneath the ice of 8 lakes;
- 2) beneath and within the ice of 7 aufeis formations;
- 3) beneath smooth ice cover over deep pools within the river channel in one drainage; and
- 4) beneath ice pressure ridges over small localized pools within river channels.

Pressure ridges in river ice were found in the Canning, Tamayariak, Katakturuk, Sadlerochit, Hulahula, Okpilak, and Jago river drainages. After the initial association was made between pressure ridges and the presence of water, water was documented throughout extensive reaches of most of these rivers. The ridges generally appeared to be within the primary channel of these rivers, quite often in highly braided areas. In many instances, a series of ridges were observed following the course of a main channel. Based on radar records, water was confined to the area directly

¹The use of trade names of commercial products in this report does not constitute endorsement or a recommendation for use by the Federal Government.

beneath a ridge, and was not present to either side, or immediately upstream or downstream from the ridge.

The following describes the results of the inventory effort by each river drainage investigated.

Canning River

Most of the Canning River between the 1002 boundary and latitude 69°55' appeared to be a continuous bank to bank icing (Figure 2). Sub-ice water was identified within the main channel as well as in secondary channels at each of the 13 cross-sectional transects flown across this portion of the river. At several locations water was identified at shallow depths within thick ice, indicating flow through conduits in the icing. Water overflow was observed on the icing surface at several locations in this reach and was readily identified at a distance by rising water vapor.

Water was found at all transects within the highly braided reach north of latitude 69°55'. All of the sites where water was found within this reach were beneath pressure ridges, with water detected beneath 17 of the 34 (50%) ridges measured. Water was also detected beneath 6 of the 7 pressure ridges measured in the lower portion of the eastern channels. The presence of aufeis was observed only in the upper portion of the braided reach.

Between the lower extent of the major braided area and the Canning River delta, the ice surface was flat, with no evidence of pressure ridges. No definitive indication of sub-ice water was found along any of the four transects in this reach.

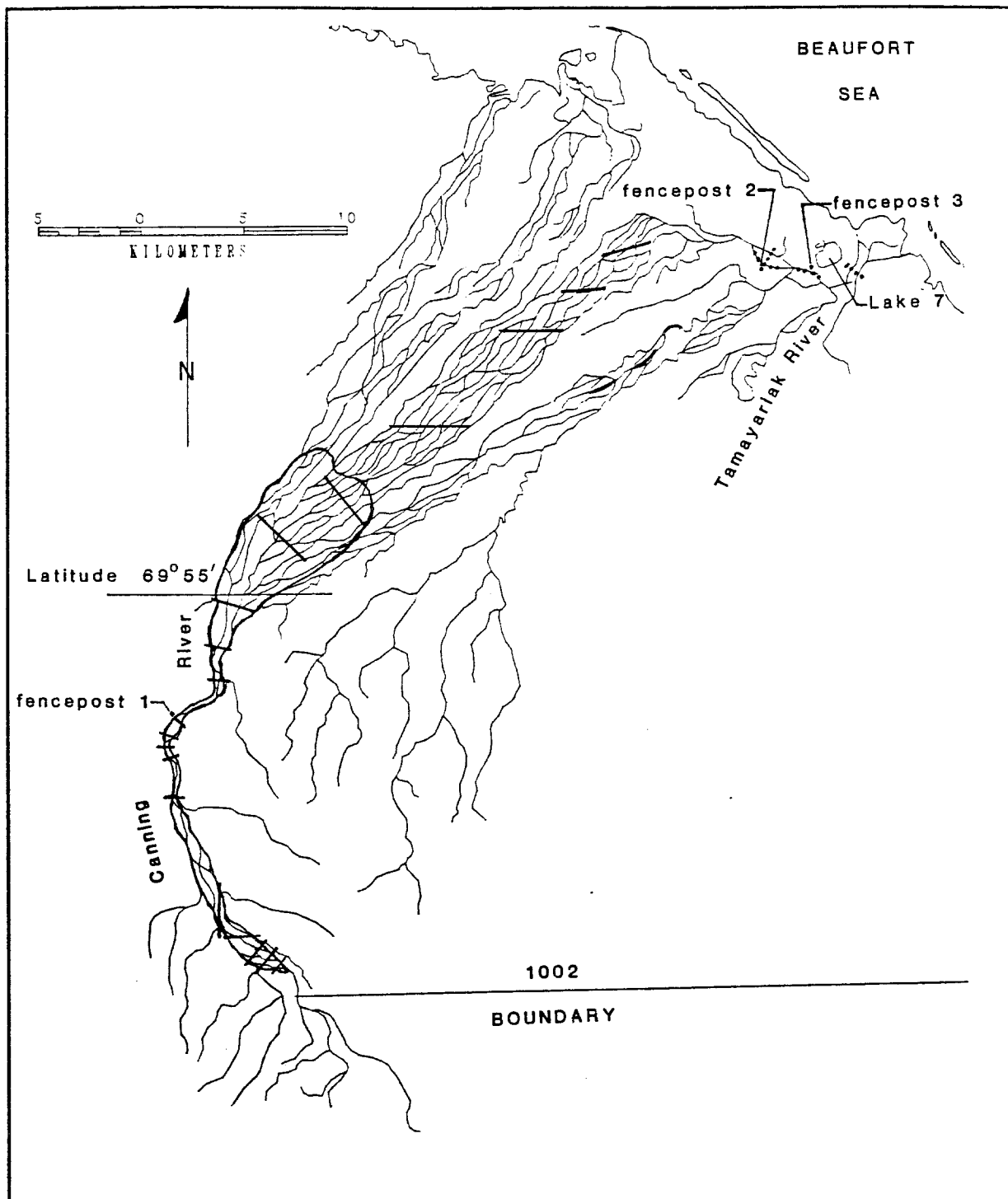


Figure 2.--Canning River drainage within the 1002 area illustrating the location of transects where water was present (solid lines) and not present (dotted lines) and location of icings (closed polygons).

Tamayariak River

Water was found in association with aufeis, river pools, and pressure ridges in the Tamayariak River (Figure 3). Water was detected along all 3 transects flown over the aufeis formation on the mainstem under both flat ice and pressure ridges. Unmeasured pressure ridges were observed in the braided reach between the aufeis and the confluence of the West Fork. Two large pressure ridges were also observed about 16.1 km upstream from the icing. Water was detected beneath 3 of the 6 pressure ridges measured along two transects downstream from the confluence of the West Fork. Water was detected beneath flat ice along two transects near fencepost number 4. The radar record indicated the pools were approximately 150 and 380 m long. At the 150 m pool, 8 cm of water was measured beneath 1.4 m of ice, conductivity was 70 umhos/cm, and salinity was near zero (Figure 4). No water was detected along the transect downstream from fencepost 4.

Water was found in the West Fork of the Tamayariak River in a small aufeis formation and beneath pressure ridges. Between the icing and the confluence with the mainstem, water was detected beneath 14 of 22 (64%) pressure ridges. Unmeasured pressure ridges were observed for up to 5 km upstream from the West Fork icing.

Katakturuk River

Pressure ridges were found at five locations within the lower 16 km of the Katakturuk River (Figure 5). Twenty out of 30 (67%) pressure ridges were found to have water beneath them.

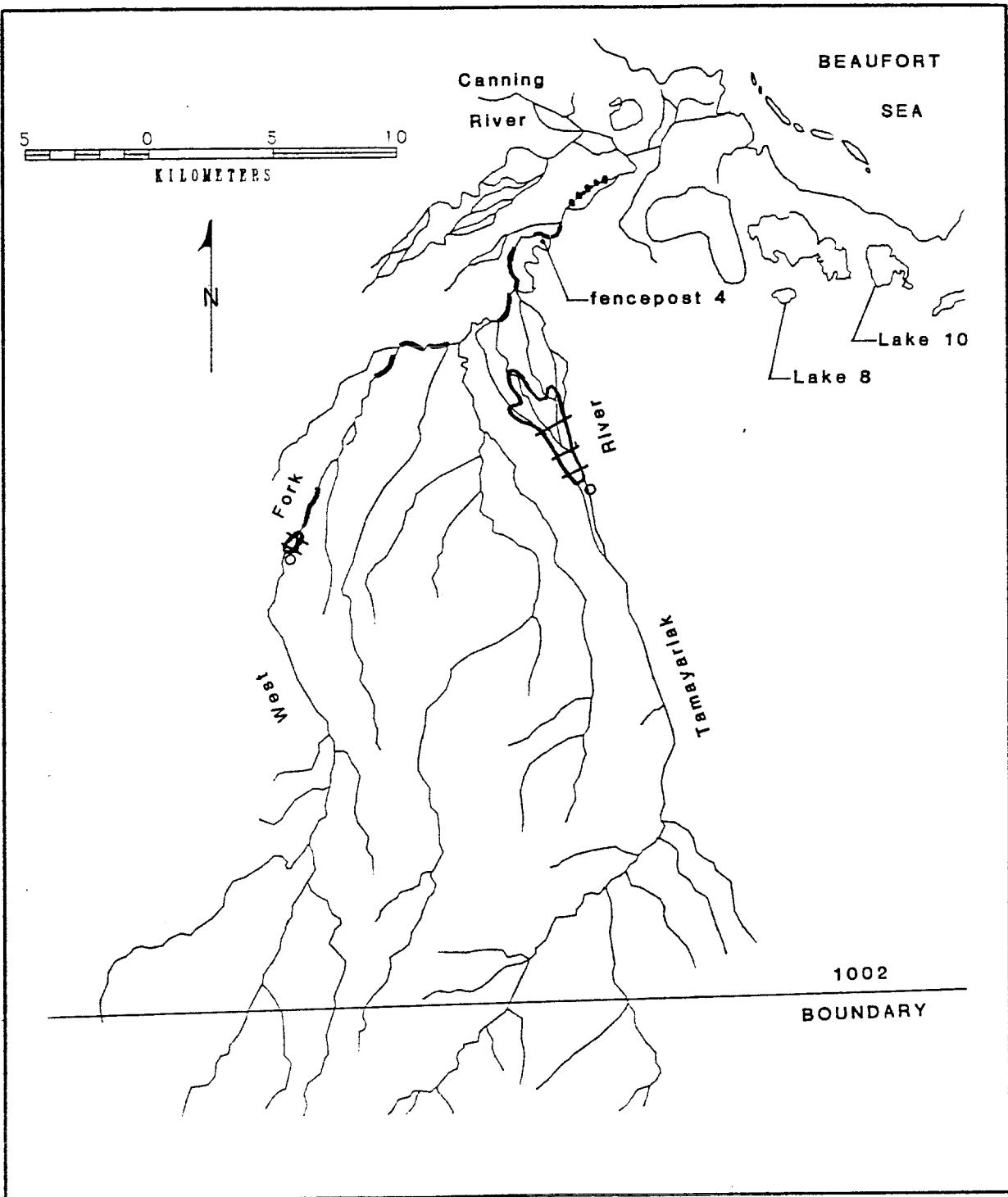


Figure 3.--Map of the Tamayariak River drainage illustrating the location of transects where water was present (solid lines) and not present (dotted line) and location of icings (closed polygons) and springs (circles).



Figure 4.--Ice thickness and water depth being measured at Tamayariak River pool located at fence post number 4 using weighted tape measure. The radar antenna can be seen mounted on the right side of the helicopter.

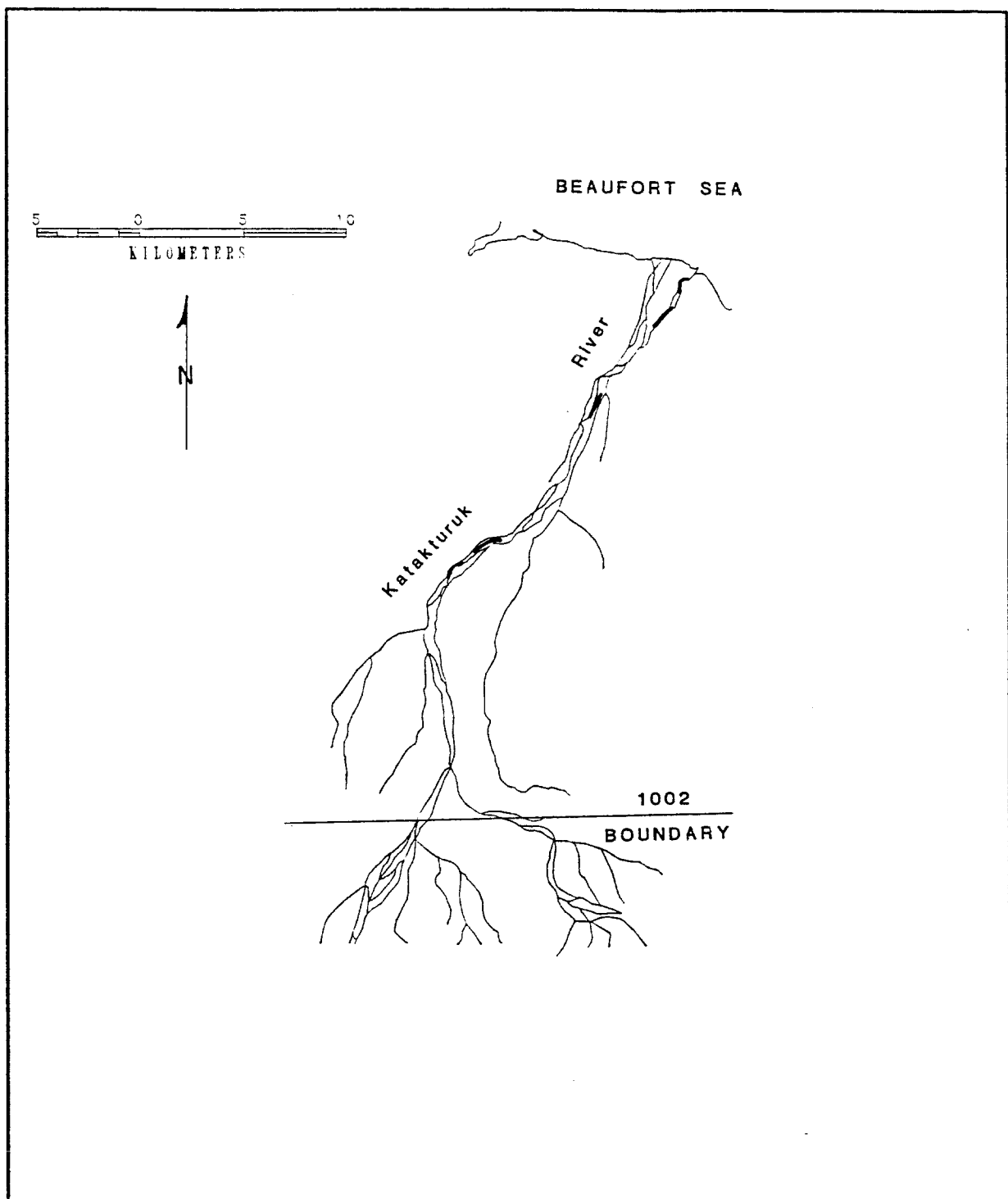


Figure 5.--Katakaturuk River drainage within the 1002 area illustrating the location of transects where water was present (solid lines).

Sadlerochit River

Water was found throughout the portion of the Sadlerochit River within the 1002 area (Figure 6). An aufeis formation was identified on the Sadlerochit River about 9.7 km downstream from the 1002 boundary. Water was found throughout this icing, especially beneath pressure ridges. Out of 15 pressure ridges measured along one transect through the length of this icing, 13 (87%) were found to have water beneath them.

Water was identified under the ice at two locations between the icing and the southern 1002 boundary. Between the icing and the mouth of the river, water was identified beneath 26 of 41 (63%) pressure ridges measured.

A transect grid was flown over two large pressure ridges located at fence post number 6 about 3.2 km above the river's mouth. Water was found only directly beneath each ridge, with no water identified immediately upstream, downstream, or on either side of the ridges. The height of these ridges was 2.2 m and 2.7 m above the surrounding level ice surface. Water depths of 1.2 m and over 1.2 m were measured beneath the two ridges through drilled auger holes (Figure 7).

Sadlerochit Spring and Itkilyariak Creeks

Water was found throughout Sadlerochit Spring Creek and downstream through Itkilyariak Creek to its confluence with the Sadlerochit River. Sadlerochit Spring Creek was ice free for approximately 5 km between its source and the large aufeis formation. Water was present at multiple locations along each transect through the central portion of the aufeis formation, some of which were confined in shallow conduits within the icing. Water vapor was observed in patches on the surface of the lower portion of

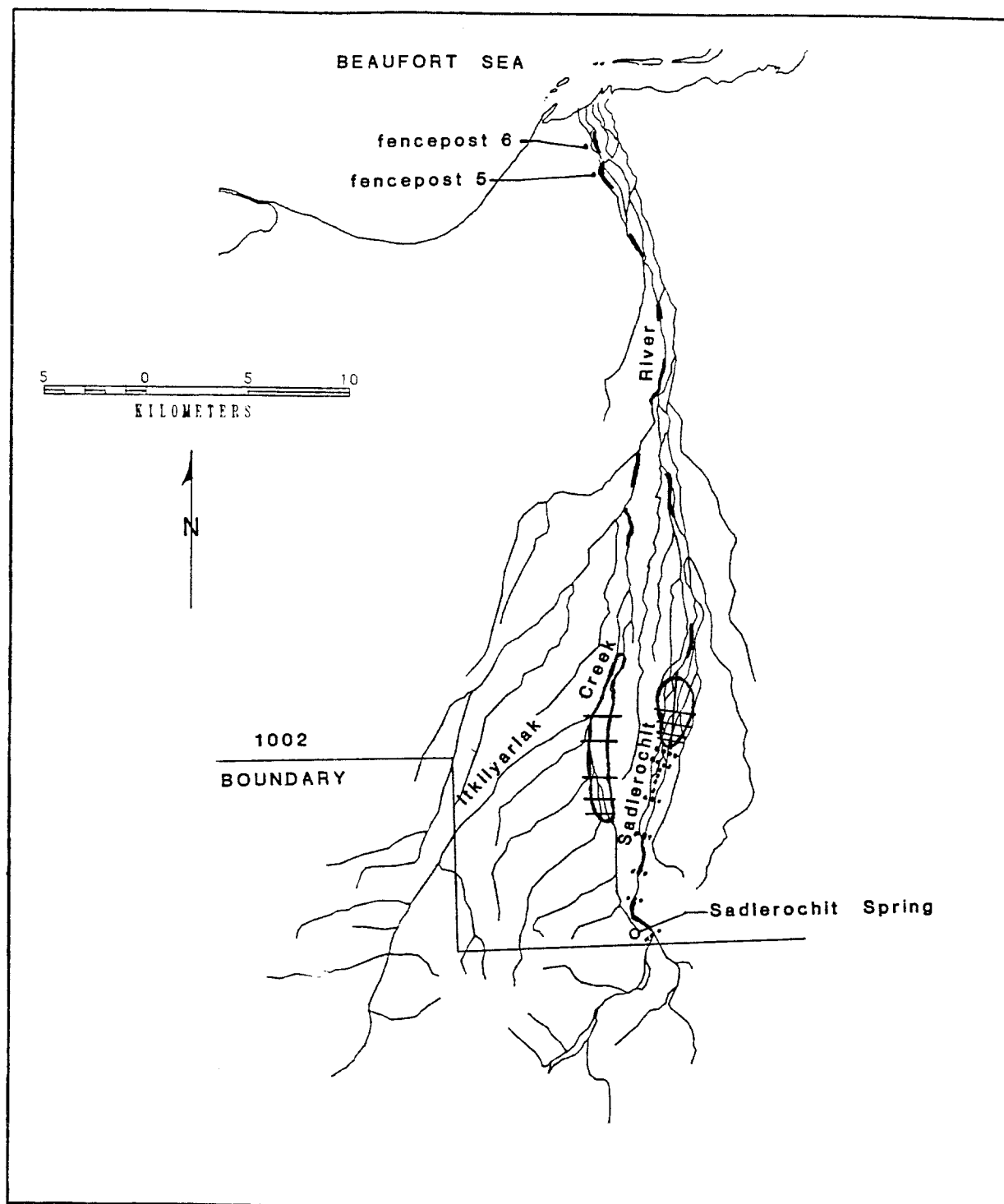


Figure 6.--Sadlerochit River drainage within the 1002 area illustrating the location of transects where water was present (solid lines) and not present (dotted lines) and location of the icings (closed polygons) and spring (circle).



Figure 7.--Ice auger being used to drill a hole through the largest pressure ridge on the Sadlerochit River at fence post number 6. More pressure ridges can be seen in the background looking upstream.

the icing. Pressure ridges were observed throughout the remainder of Itekilyariak Creek and water was identified beneath 9 of 13 (69%) ridges measured in the lower 6.4 km of the stream.

Hulahula River

Water was identified throughout much of the Hulahula River within the 1002 area (Figure 8). At Fish Hole 1, ice-free spring flow was observed along the west bank at the upper end of the aufeis formation within the primary river channel. Several cross sectional transects across the upper and central portion of the aufeis formation revealed the presence of water at several points along each transect.

Pressure ridges were observed throughout the river reach from the aufeis formation downstream to just above the Okpilak River confluence. Water was detected at all 11 transects flown in that reach, with 39 of 52 (75%) ridges measured having water beneath them. Water was also detected beneath 3 of 4 low pressure ridges between the icing and the southern 1002 boundary. No pressure ridges were observed in the Hulahula River delta and upstream for 3.2 km.

Okpilak River

Possible radar reflections from water were noted beneath pressure ridges at two locations on the Okpilak River, about 9.7 km upstream from the river's mouth (Figure 8). The sub-ice reflections on the graphic display of the radar record at these locations were of marginal intensity and may only represent ice grounded on an unfrozen substrate. Pressure ridges were also found at a few other scattered locations in this drainage, but no water was

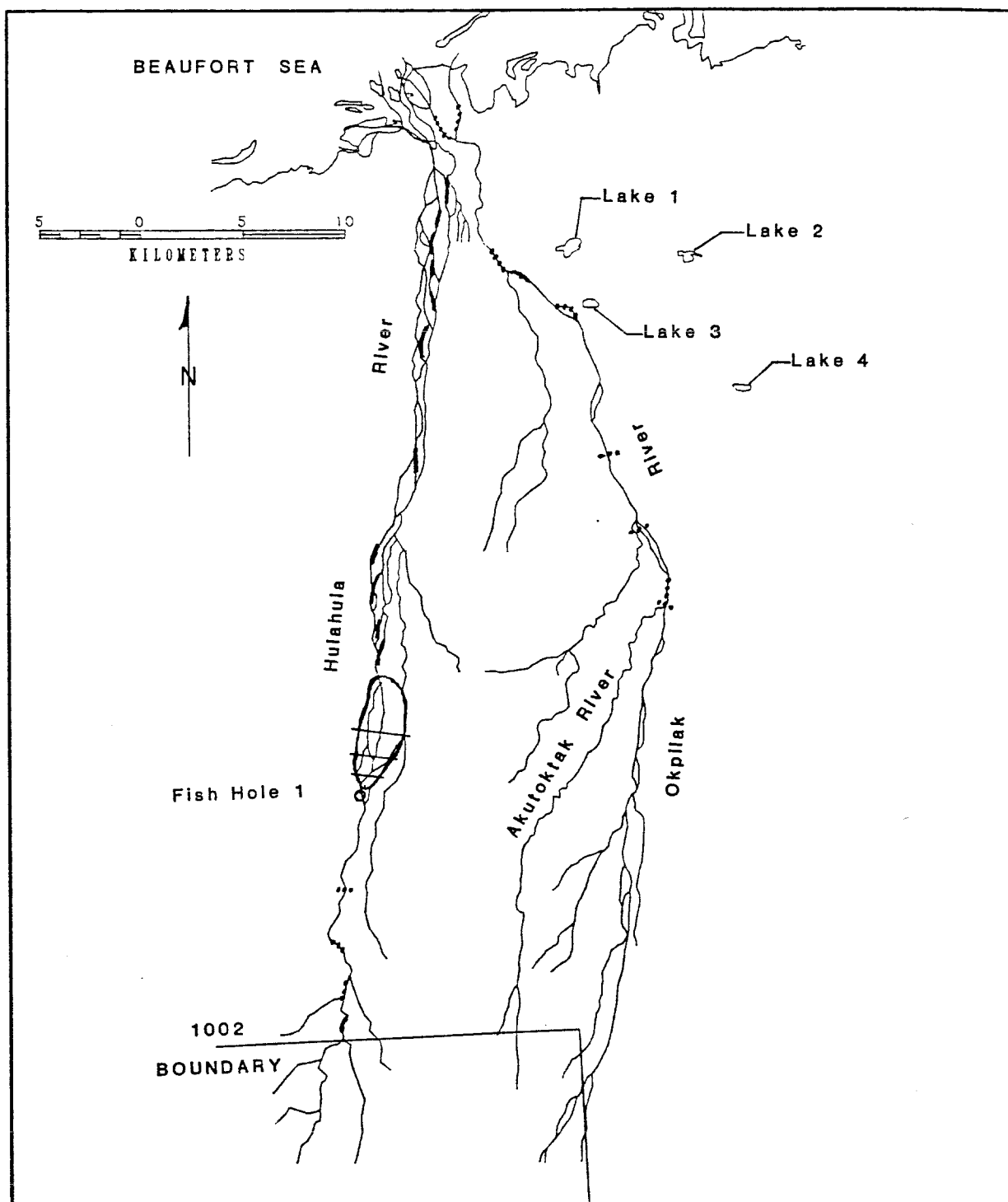


Figure 8.--Hulahula and Okpilak river drainages within the 1002 area illustrating the location of transects where water was present (solid lines) and not present (dotted lines) and the location of the icing (closed polygon) and spring (circle).

identified in association with them. No indication of water was identified at any of the remaining transects in this drainage.

Jago River and Okpirourak Creek

Inventory of the Jago River drainage for the presence of water was restricted to a 14.5 km reach from the confluence of Okpirourak Creek downstream to the confluence of the Okerokovik River (Figure 9). Two longitudinal transects were flown over pressure ridges in this reach, and water was identified beneath 8 of 12 (67%) ridges measured.

No water was detected along two transects flown across meander bends in Okpirourak Creek just above its confluence with the Jago River.

Okerokovik River Spring Icing

Two cross sectional transects across the aufeis formation indicated water was present (Figure 9). Water was present beneath two large pressure ridges in the center of the icing. No open channels were observed in the spring area at the head of the aufeis formation.

Niguanak River

The lower 24 km of the Niguanak River (Figure 9) was visually inspected from the air and no pressure ridges were observed.

Lakes

Water was noted in 8 of 10 lakes surveyed (Table 2). Three lakes near the mouth of the Canning River (lakes 7, 8, and 10) were found to have water beneath the ice (Figures 2 and 3). Out of four lakes (lakes 1-4) surveyed to

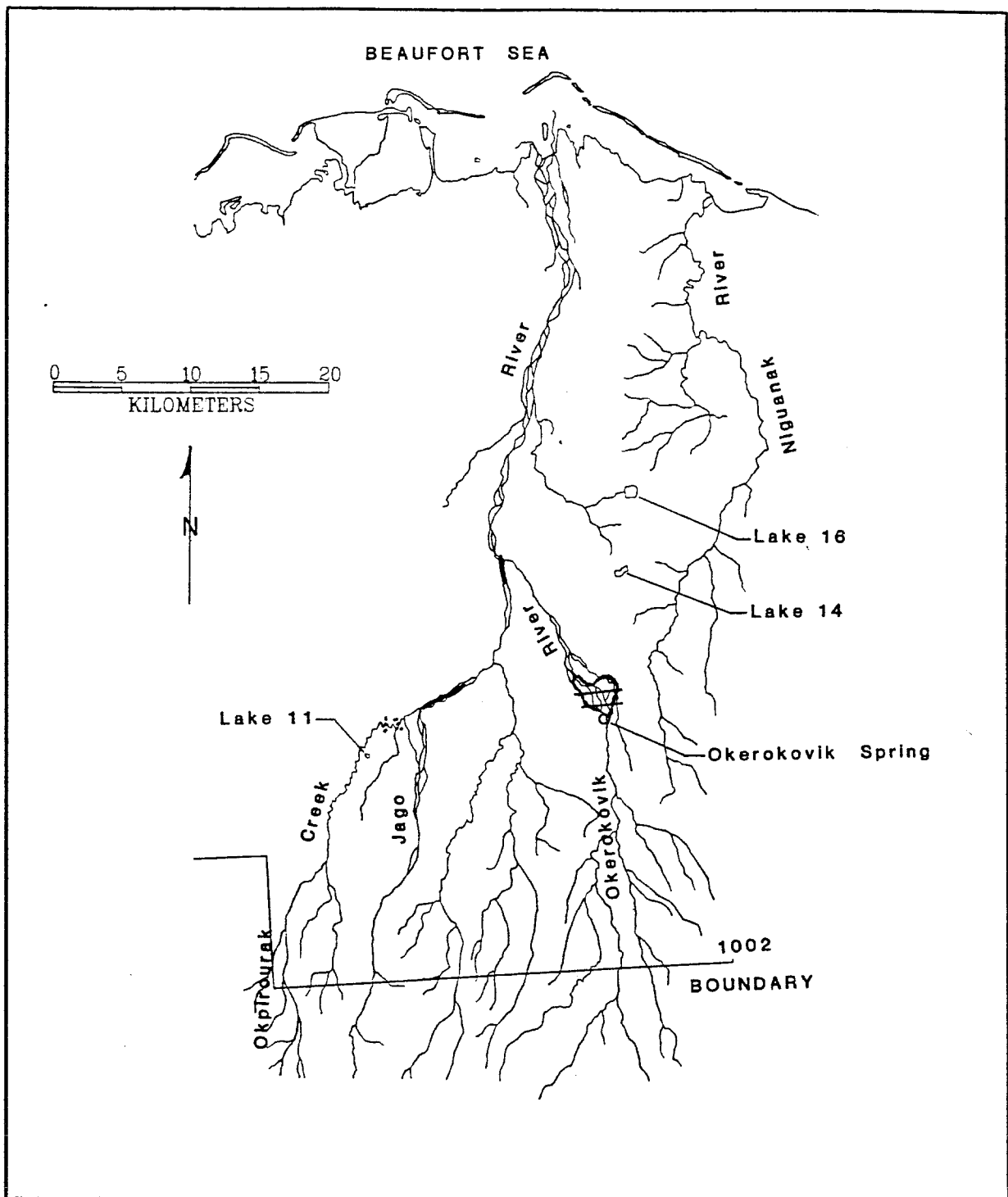


Figure 9.--Jago and Niguanak river drainages within the 1002 area illustrating the location of transects where water was present (solid lines) and not present (dotted lines) and the location of the icing (closed polygon) and spring (circle).

Table 2. Number, location, water presence, and minimum and maximum ice thickness of lakes surveyed by radar, during March 25-30, 1988.

Lake No.	Location		Water Present	<u>Ice Thickness (m)</u>	
				Minimum	Maximum
1	NE1/4	Sec. 3 T7N R33E	Yes	1.25	1.55
2	SW1/4	Sec. 11 T7N R33E	Yes	1.34	1.43
3	Center	Sec. 5 T7N R33E	No	0.73	1.01
4	SW1/4	Sec. 27 T7N R34E	Yes	1.37	1.71
7	E1/2	Sec. 10 T8N R26E	Yes	1.49	1.68
8	NE1/4	Sec. 5 T7N R27E	Yes	1.40	1.55
10	W1/2	Sec. 35 T8N R27E	Yes	1.46	1.65
11	SE1/4	Sec. 11 T4N R34E	No	1.13	1.22
14	SE1/4	Sec. 32 T6N R36E	Yes	1.34	1.65
16	NW1/4	Sec. 16 T6N R36E	Yes	1.31	1.65

the east of the Okpilak River, all but lake 3 were found to have water present (Figure 8). A small lake (lake 11) about 5 km upstream from the mouth of Okpirourak Creek was frozen to the bottom (Figure 9). Two lakes on Niguanak Ridge (lakes 14 and 16) were found to have water present (Figure 9). Ice thickness in lake 16 was measured through two holes drilled through the ice. The ice was 1.75 m thick at each location and water depth beneath the ice was 7.6 and 17.7 cm respectively. For lakes in which sub-ice water was identified, ice thickness ranged from 1.25 to 1.71 m.

Discussion

The presence of water throughout a large portion of the 1002 area was documented during late winter when ice development was at or near maximum. Water was identified in a variety of settings that were both expected and unexpected prior to the inventory.

The presence of flowing water and icings at Sadlerochit Spring and Hulahula Fish Hole 1 Spring and the springs on the Okerokovik, Tamayariak, and Canning rivers have been previously reported (Childers et al. 1977; Dean 1984). However, the icings on the Sadlerochit and West Fork of the Tamayariak rivers have not been previously reported.

The Sadlerochit and West Fork of the Tamayariak icings apparently were not large enough to persist into the summer as residual icings identified by Dean (1984) from satellite imagery. The portion of the Canning River from the southern 1002 boundary downstream to latitude 69°55' contained more extensive icing than expected. Within that reach, the continuous presence of aufeis and the occurrence of water at all of the radar transects indicates

that water flow was most likely continuous throughout this area. The winter movement and residence of radio-tagged Arctic grayling within this portion of the Canning River (Wiswar et al. in preparation) and the diversity of fish species inhabiting the Canning River (West and Fruge in preparation) supports the importance of the observed water flow to resident and anadromous fish populations.

With the exception of a few large lakes to the east of the Canning River delta, most of the lakes on the 1002 area are thought to have basins less than 2 m deep and freeze to the bottom by late winter (Clough et al. 1987). The results of the lake surveys conducted during this inventory indicate that water is present beneath the ice of several smaller lakes in the area, although the depth of sub-ice water in all but one and water quality were not measured. The range of measured lake ice thickness (1.25 to 1.71 m) during this survey may be an indication of a mild winter. The average temperature at the Barter Island weather station was 2.8°C above normal for the period from October 1987 through March 1988 (National Oceanic and Atmospheric Administration 1987 and 1988).

The presence of water in deep river pools has been documented in other north slope drainages but not within the 1002 area. Overwintering habitat for fish was suspected in the lower portion of the Tamayariak River (Wilson and Kelly in preparation) but not documented. During this inventory, water was documented in deep river pools at only two sites, in the lower Tamayariak River adjacent to fencepost number 4. The low conductivity and salinity measured at one of these sites indicates that there was no sea water intrusion and that water quality may be suitable for resident fish.

The presence of water in association with pressure ridges was not anticipated prior to this inventory and no documentation of this situation could be found. However, pressure ridge pools accounted for the most frequent and widespread occurrence of water identified within the 1002 area during this inventory.

The documentation of numerous localized pools of water throughout portions of several river drainages where none was previously thought to occur raises some new possibilities regarding the winter distribution of fish in those areas. The fall movements of radio-tagged grayling from the lower Tamayariak and Akutoktak rivers and Itkilyariak Creek involve complex and lengthy migrations to overwintering areas (Wiswar et al. in preparation). It is unlikely that young-of-the-year grayling produced in these streams would be physically able to migrate to the locations documented for adult fish. The pools of water found beneath pressure ridges in the lower Tamayariak, Hulahula, and Sadlerochit rivers and Itkilyariak Creek may provide overwintering habitat for young-of-the-year grayling from those drainages, as well as larger fish, providing water quality and volume are adequate. A population of age 1 and 2 grayling were found residing in an upper Tamayariak River tributary immediately after high breakup flows during 1988 (Corning in preparation). The presence of this population of small juvenile fish within 2 km of the pressure ridges observed in the upper Tamayariak mainstem offers further support to the possibility that pressure ridge pools may provide overwinter habitat.

Several limitations with the gear and time available to conduct the field work restricted the inventory of winter water in the 1002 area. The helicopter mounted radar system used to determine ice thickness and sub-ice

water presence was an effective tool to measure those parameters. However, measurement of sub-ice water depth, and thus a means to quantify water volume, was not possible with the antenna configuration used. Time constraints limited the extent of radar coverage of several drainages, notably the upper Tamayariak, Katakturuk, and Jago rivers.

Difficulties with the operation of the global positioning system restricted the acquisition of accurate position locations for many of the transects. Its operation was limited to a 3-4 hour time window when the required number of satellites were "visible" above the southern horizon. The unexpected loss of a "lock" on the required number of satellites during the operational time frame resulted in erroneous positions and a lack of confidence in other positions that could not be verified from topographic features. Drifted snow obscured most of the lake margins, greatly restricting the effort to visually locate many of the lakes intended for survey.

The results of this inventory indicate several gaps in the existing winter water availability data base that warrant further investigation:

1. A more detailed inventory of the distribution of pressure ridges in all drainages in the 1002 area;
2. Quantification of water volumes beneath pressure ridges and investigation of any correlation between pressure ridge size and volume;
3. Investigation of late winter water quality of pressure ridge pools and lakes to ascertain their suitability as fish overwintering habitat;
4. Investigation of the annual reoccurrence of pressure ridges in the same locations; and

5. A complete inventory of all lakes that are deep enough to keep from freezing to the bottom.

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